Structure-Enhancing Visualization for Manual Registration in Fluoroscopy

Matthias Hoffmann[1], Felix Bourier[2], Norbert Strobel[3], Joachim Hornegger[1,4]

[1]Pattern Recognition Lab, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany
[2]Krankenhaus Barmherzige Brüder, Regensburg, Germany
[3]Siemens AG, Healthcare Sector, Forchheim, Germany
[4]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Erlangen, Germany
matthias.hoffmann@cs.fau.de

Abstract. Electrophysiology procedures are in many cases performed under fluoroscopic guidance. As the heart is not visible under fluoroscopy, a preoperatively acquired heart model of the patient may be fused with the live X-ray images to provide the physician with a better orientation. This heart model needs to be registered to the fluoroscopic images. Currently, registration is performed manually, e.g., after contrast injection into the left atrium during atrial fibrillation procedures. We propose a novel visualization of the heart model that shows the same structures as the contrast agent and allows an easy identification of corresponding landmarks and features in both the model and the angiography images.

1 Introduction

Pulmonary vein isolation is the standard treatment of paroxysmal atrial fibrillation (Afib) [1]. Afib is the most common heart arrhythmia affecting more than 2.2 million people in the US alone [2]. Ablation is usually performed under fluoroscopic guidance using a C-arm system. Unfortunately, fluoroscopy shows only the catheters, while the left atrium remains invisible without the injection of contrast agent. A mapping system [3] can be used to generate a model of the left atrium and to show the position of the catheters with respect to this model. Their use, however, increases the cost of the intervention. Besides or in addition to using a mapping system, the orientation of the physician can also be improved by fusing the live X-ray images with a 3-D heart model of the patient. A 2-D image of this model can be rendered using the same camera perspective as the fluoroscopic system. This image is used as overlay for the fluoroscopic images and provides an outline of the patients heart [4,5]. The 3-D heart model is in many cases acquired preoperatively using CT or MRI. Since the patient is not positioned exactly the same way during acquisition of the model and intervention, the 3-D heart model has to be registered to the coordinate system of the fluoroscopic system. This applies also if the patient moves during the intervention.

H.-P. Meinzer et al. (Hrsg.), Bildverarbeitung für die Medizin 2013, Informatik aktuell, pages 241 - 246 DOI: 10.1007/978-3-642-36480-8_43, (C) Springer-Verlag Berlin Heidelberg 2013. The final publication is available at link.springer.com

Currently, registration is performed by capturing a biplane fluoroscopic sequence while contrast agent is injected into the left atrium. The contrast agent flows through the heart and outlines the structure of the left atrium. Then, the overlay's position is adjusted until it fits to the structure shown by the contrast agent.

Unfortunately, there may be cases, where the whole shape of the left atrium is not well outlined by the contrast agent. This is because the contrast is used sparingly since contrast puts a burden on the kidneys. So, it may not reach all areas of the left atrium. It also mixes rapidly with the blood inside the left atrium often leaving only a diffuse shadow of its anatomy. The most dominant structures highlighted by the contrast agent are edges in the left atrium.

Current fluoroscopy overlays depict a rendering of the heart model. To reveal internal structures, techniques such as adaptive clipping techniques [6] can be used. The overlay may occlude the view to the fluoroscopic image. Increasing the transparency of the overlay usually improves the visibility of the fluoroscopic image. However, the edges of the pulmonary veins and other important features are more difficult to see such that it predominantly shows the outline of the heart. Also the identification of corresponding parts of the heart model in the two views requires an experienced user.

We present a novel overlay that helps also unexperienced users to achieve reliable alignment of the heart model to the structures highlighted by the contrast agent. The overlay highlights edges that potentially could be outlined by contrast agent. The edges are colored according to their position in 3-D space such that an easy identification of corresponding parts in both views is possible. This overlay method is described for models of the left atrium but can also be applied to other organs. The contribution is structured as follows. In the second section, details on the overlay generation as well as the method for evaluation are provided. The results are presented in section three. In the final section, we discuss our results and draw some conclusions.

2 Materials and Methods

The left atrium model is represented as a triangle mesh, information about the camera geometry is provided by a 3×4 projection matrix for both views A and B. In section 2.1 we present which structures are selected for display, in section 2.2 the color scheme is explained.

2.1 Structure Selection

The edges that may become visible by a contrast agent injection depend on the viewing direction of the C-arm. The direction is defined by the projection matrix $\boldsymbol{P} \in \mathbb{R}^{3\times4}$. The optical center $\boldsymbol{o} \in \mathbb{R}^3$ is given as the null space of the projection matrix

$$\boldsymbol{o} = \mathrm{Null}(\boldsymbol{P}). \tag{1}$$

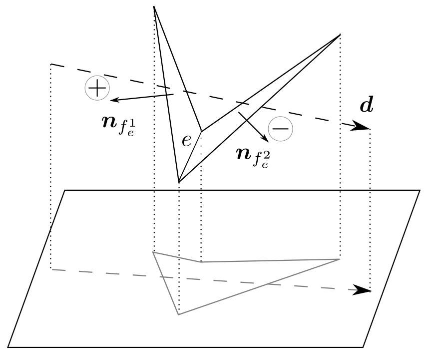


Fig. 1. Depending on the viewing direction $\boldsymbol{d}$ and the normals $\boldsymbol{n}_{f_e^1}$, $\boldsymbol{n}_{f_e^2}$ of the adjacent faces, an edge of the mesh is visible in the 2-D. If the results of the scalar products of $\boldsymbol{d}$ with each normal vector have different signs, the edge is visible in 2-D.

The viewing direction $\boldsymbol{d}_{\boldsymbol{x}}$ to a point $x \in \mathbb{R}^3$ can be easily computed by the difference vector

$$\boldsymbol{d}_{\boldsymbol{x}} = \boldsymbol{x} - \boldsymbol{o} \tag{2}$$

To determine, if an edge $e = (\boldsymbol{e}_1, \boldsymbol{e}_2)$ of the mesh, defined by two points $\boldsymbol{e}_1, \boldsymbol{e}_{,2} \in \mathbb{R}^3$ is visible as edge from the perspective of the camera center, the normals $\boldsymbol{n}_{f_e^1}$ and $\boldsymbol{n}_{f_e^2}$ of the two faces f_e^1 and f_e^2 which are adjacent to e are considered. If the results of the scalar products of $\boldsymbol{d}$ with $\boldsymbol{n}_{f_e^1}$ and $\boldsymbol{n}_{f_e^2}$, respectively, have different signs, the edge is visible in the 2-D projection [7]. Therefore the set E of visible edges is given by

$$E = \left\{ e \mid \mathrm{sgn}(d_{\boldsymbol{e}_1}^T \boldsymbol{n}_{f_e^1}) \neq \mathrm{sgn}(d_{\boldsymbol{e}_1}^T \boldsymbol{n}_{f_e^2}) \right\} \tag{3}$$

2.2 Color scheme

When the edges are displayed as parts of a fluoroscopy overlay image, they might cross if there are overlapping structures in the heart. This could happen when a pulmonary vein lies before the heart wall. To differentiate between overlapping details, it helps to color edges belonging to the same structures similarly. On possible solution may be coloring depending on the perspective depth of the edge. This would present additional depth information to the physician which is difficult to derive from 2-D projections only. However, due to the different orientations of the biplane views, the same structures would be colored differently in both images, since they have different distances to each camera center.

To avoid this kind of confusion, we color edges according to their position in 3-D space. When choosing the color scheme, it is important that an edge does not assume a color with a low saturation, because it would be hard to see it in the grayscale fluoroscopic image. Especially white and black colors should be avoided. We chose a color encoding in which the coordinate of a point along the patients left-right axis corresponds to the green intensity, the coordinate along the front-back-axis corresponds to the blue intensity and the red intensity is fixed. The relationship of 3-D points along the head-feet axis is preserved in the projection. I.e. a 3-D point $\boldsymbol{a}$ that is nearer to the head than a point $\boldsymbol{b}$ will also be located nearer to the top border of the projection images. Therefore, it does not need to be encoded in color. Using this color scheme, colors with a high saturation occur at salient features like pulmonary veins.

2.3 Evaluation Method

The goal of the evaluation was to test if people that are familiar with images from EP procedures can do a registration more accurately using the novel overlay compared to an overlay just showing the outline of the heart model. To evaluate this, five people working with these images on a regular basis were asked to do a manual registration on six images acquired during atrial fibrillation procedures using the overlay showing just the overall outline followed by a manual registration of the six images using the edge-enhancing approach. To make the registration easier, also a subtraction image showing only the contrast agent could be displayed. For each biplane image pair, a registration performed by a specialized physician was available as gold standard. The registration is restricted to 3-D translation as it is typically done in clinical practice [8].

3 Results

The results of the evaluation are presented in Fig. 2. The error is given as difference between the registration done by the user and the reference registration. The mean error and the standard deviation for each sequence is given for both overlay types.

4 Discussion

The results show that the use of the new overlay allows a more precise manual registration. For every sequence the mean error decreased, even if in some cases

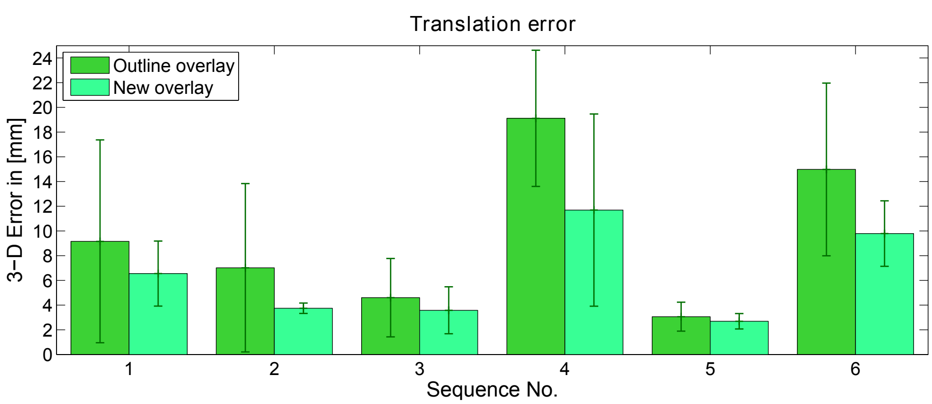
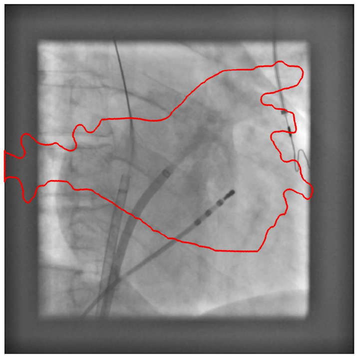
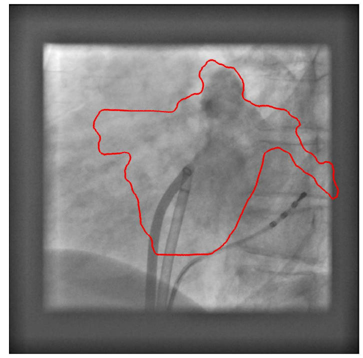


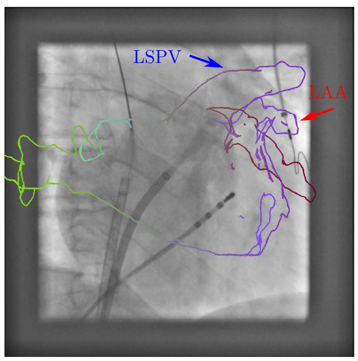
Fig. 2. Mean translational error in mm and standard deviation of the mesh registration using the outline overlay and the structure enhancing mesh overlay.



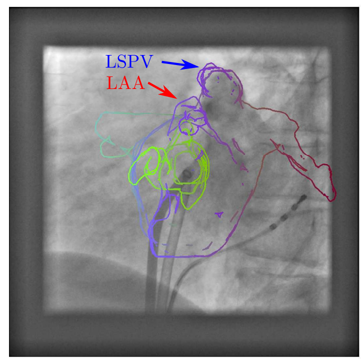
(a) View A with overlay showing the outline.



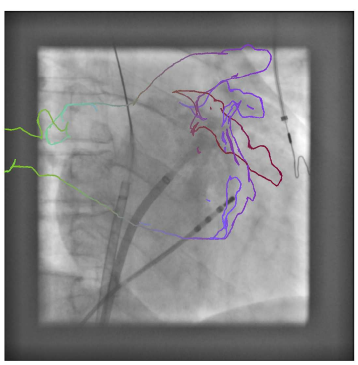
(b) View B with overlay showing the outline.



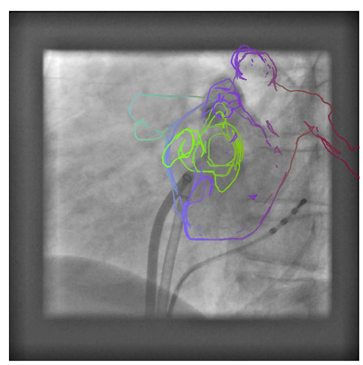
(c) View A with new overlay showing colored edges.



(d) View B with new overlay showing colored edges.



(e) View A with correctly registered overlay.



(f) View B with correctly registered overlay.

Fig. 3. Using the overlay showing only the outline, the registration results given in 3(a) and 3(b) seem to be correct. When using the structure enhancing overlay, one can see that the left superior pulmonary vein (LSPV) in 3(c) is uncontrasted while it is filled with contrast agent in 3(d). Instead, the left atrial appendage (LAA) is the contrasted structure. By aligning the overlays such that the LAA is filled with contrast agent in both images, a correct registration, 3(e) and 3(f), is achieved.

the error increased for a single user. The least decrease is found at sequence 5. Here, the structure shown by the contrast agent contained a greater part of the overall outline such that it was possible to do a good registration based on the outline overlay. The most decrease can be found for sequence 4. All users made a registration where the contrast agent is registered in one view to the left atrial appendage and in the other view to the left superior pulmonary vein (Fig. 3). The new overlay revealed the shape of the left atrial appendage and by searching for correspondences, two users were able to notice this mistake and correct it.

To conclude, the main contribution of the new overlay are following two features: 1.) The edges shown by the overlay provides the user additional structures he can register to and 2.) the coloring scheme allows the user to check if in both images the same heart region is highlighted by the contrast agent.

Acknowledgments. This work was supported by the German Federal Ministry of Education and Research (BMBF) in the context of the initiative Spitzencluster Medical Valley - Europäische Metropolregion Nürnberg, project grant Nos. 01EX1012A and 01EX1012E, respectively. Additional funding was provided by Siemens AG, Healthcare Sector.

Disclaimer: The concepts and information presented in this paper are based on research and are not commercially available.

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